Laboratory Investigation for the Effects of Using Fiber Reinforcement in Rigid Pavements on Compressive and Flexural Properties

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Abstract

Rigid pavements provide durable service life and have remarkable application under heavy traffic loading. But, though the rigid pavements have several advantages, it suffers from some disadvantages that are relating with concrete is brittle material. One solution have been carried out in order to overcome this problem is using fibers reinforced to improve tensile strength and provides ductility. The main objective of this study is to investigating the effects of using fiber reinforced concrete (Polyvinyl alcohol and steel fiber) in Rigid Pavements on Compressive and Flexural Properties. The study results shown the compressive strength has been increased by (20%) when adding (0.5%) of Polyvinyl alcohol concrete mixture. While modulus of elasticity has been decreasing by (23%) when adding the same content of Polyvinyl alcohol. On the other hand, the study results show that using steel fiber (1.5%) in concrete mixtures increase compressive strength by more than 145%.However modulus of elasticity slightly decrease. Also the addition of PVA fiber by 0.5% increase of about (51%) in the Modulus of Rupture, while using steel fiber (1.5%) increase Modulus of Rupture by more than (24%).

Keywords: Rigid Pavement, fibers reinforced, Polyvinyl alcohol, and steel fiber.

الخلاصة

أن التبليط الكونكريتي يوفر ديمومة طويلة الأمد ومقاومة للأحمال المرورية العالية، ولكن بالرغم من تلك الميزات فأن التبليط الكونكريتي يعاني من بعض المشاكل التي تتعلق بمقاومة الكونكريت الضعيفة للأنحناءات. أن احدى الحلول المتبعة للتغلب على تلك المشكلة هي تقوية الكونكريت بالالياف لغرض زيادة مقاومته للأنحناءات ولتزويده بالليونة المطلوبة. أن الهدف الرئيسي من هذه الدراسة هو دراسة تأثير أستخدام الألياف المقوية في التبليط الكونكريتي على خواص الأنضغاط والأنحناء للخلطة الكونكريتية. نتائج الدراسة بينت أن مقاومة الأنضغاط تزداد بمقدار (20%) عند أضافة (0،5%) من ألياف البوليفينيل الكحول للخلطة الكونكريتية، بينما أن معامل المرونة يقل بمقدار (23%) بأضافة نفس النسبة من أليافالبوليفينيلالكحول. من ناحية أخرى، فقد بينت نتائج الدراسة ان أضافة ألياف الحديد بنسبة (1،5%) للخلطة الكونكريتية سيزيد مقاومة الأنضغاط بمقدار (45%)، بينما أن معامل المرونة يتأثر بشكل طفيف جداً من أضافة تلك الألياف.أيضاً ان أضافة (0,5%) من ألياف البوليفينيل الكحول سيزيد معامل الكسر بمقدار (51%)، بينما أستخدام (1,5%) من ألياف الحديد سيزيد معامل الكسر بمقدار (24%).

الكلمات المفتاحية: التبليط الكونكريتي، الألياف المقوية، أليافالبوليفينيل ألكحول،وألياف الحديد.

1. Introduction

Concrete is the most popular material used in construction in general and rigid pavements in particular. Rigid pavements provide durable service life and have remarkable application under heavy traffic loading. Though the rigid pavements have several advantages, it suffers from major disadvantages **(Hui Li *et. al.*,2006)**.Concrete is considered to be a relatively brittle material, so it is prone to cracking. Many investigations have been carried out in order to overcome this problem. The inclusion of adequate fibers improves tensile strength and provides ductility **(Konig *et. al.*,1998, Ramezanianpour *et. al.*, 2006, Breitenbucher, 1996)**.

There are more investigations on the effects of different fibers on concrete properties. Some of the important effects of fibers in concrete are: increasing the compressive and tensile strength, preventing the crack development and increasing the toughness of concrete. The fundamental advantage of adding fibers to concrete is known as crack bridging **(Badr *et. al*., 2006; Daniel, 1998, Dave and Ellis, 1979, Nemkumar, and Rishi, 2006 and Stevens ,1995)**. On the other hand, the use of discrete fibers in rigid pavements application has been reported in the literature for over (40) years**(AASHTO,2001, ACI,1997, Parker, 1974, PCA, 1991, Rollings ,1981, Romualdi and Batson, 1963, Romualdi and Mandel, 1964, Skokie IL 1991, The Concrete Society ,1994, Vondran ,1991)**.

The main objective of this study is to investigating the effects of using fiber reinforced (steel fiber and Polyvinyl alcohol (PVA)) in Rigid Pavements on Compressive and Flexural Properties.

2. Fiber-reinforced concrete

Fibers have been used to reinforce materials that are weaker in tension than in compression since ancient times. Straw reinforced mud bricks were used in the Middle East as long as (10,000) years ago, and sundried adobe bricks. The first modern fiber reinforced concrete was asbestos cement, which was introduced in about (1900) with the development of the Hatschek process. However, serious theoretical studies of Fiber reinforced concrete began only in the early 1960‟s, with the work of Romualdi and his colleagues **(Romualdi& Batson 1963, Romualdi& Mandel 1964)**.

3. Fiber Types

Fiber reinforcement has been implemented in various forms of construction for thousands of years. Its roots can actually be traced back to Roman times, when straw was used as reinforcement for sun dried clay bricks. This early form of fiber reinforcement was used to improve ductility in the same manner as modern fiber reinforcement. Despite these basic similarities, a significant amount of research has been conducted to improve the performance of modern fiber reinforcement. There have been a variety of materials developed as potential fiber reinforcement over the past century. These materials include natural fibers (straw, horse hair), asbestos fibers, glass fibers, carbon fibers, steel fibers, and synthetic fibers (nylon, polypropylene, polyethylene). Each of these materials has had varied success**(Folliard *et. al*., 2006)**.

3.1 Steel Fiber Reinforcement

Steel fiber reinforcement has gone through many changes throughout its history before becoming what it is today. Typically, modern steel fiber reinforcement is produced from high tensile strength steel (greater than 130 ksi). It is generally a cold drawn wire that is deformed to a desired shape and then cut. While various deformation geometries have been developed to produce better anchorage of the fiber in the matrix, the two most common geometries used today are corrugated fibers that are sinusoidal in shape and hooked end fibers. Corrugated fibers are generally a manufacturing byproduct and therefore have lower quality control than hooked end fibers, which are produced solely for the purpose of fiber reinforced concrete. Hooked-end fibers are also typically collated into small bundles with an adhesive that breaks down during mixing and allows the fibers to distribute throughout the matrix. **(ACI, 1997)**.

Properties that are important in determining steel fiber performance are strength, stiffness, and aspect ratio. Strength and stiffness ensure proper stress development and crack width control, while the aspect ratio (length/diameter) is an important factor in understanding the bonding properties of the fibers to the matrix. Most steel fiber reinforcement today has an aspect ratio of (45 to 100), with lengths typically ranging from (2 to 3) inches. Fibers of this size typically ensure the desired failure mode of gradual bond loss and pull out of the fiber, as opposed to sudden fracture of the fiber itself. Larger aspect ratios typically are not used because they tend to lead to balling of the fiber reinforcement at higher dosages**(Folliard et. al., 2006)**.

3.2 Polyvinyl Alcohol (PVA)

Polyvinyl alcohol (PVA) fiber is known to be stable and durable in the alkaline environment of a cementitious matrix **(Garcia *et. al.*, 1997)**. These fibers are characterized by their high tensile strength (160–230psi), high modulus of elasticity (3350–5800psi), high chemical resistance to Portland cement and high affinity to water; they also present no adverse health risks **(Redon *et. al.*, 2001)**. The hydrophilicsurface of PVA fibers creates a strong chemical bond withthecementitious material. Since PVA fibers are usually stiffer thanthe concrete matrix and also provide a strong interfacial bond withthe cement matrix, they generally have a positive effect onenhancing the bending strength and other mechanical propertiesof FRCs **(Ogawa and Hoshiro 2011)**.

The high tensile strength ofPVA fibers contributes to sustaining the first-crack stress andresisting pull-out force due to the strong bond present between thefiber and the cementitious matrix. In contrast, the low lateralresistance of the fibers can lead to premature fiber rupture beforebeing pulled out of the cementitious matrix. PVA fibers elongate and transfer load to different parts ofthecementitious matrix and, as a result, the load applied isdistributed more evenly between the loading surfaces.

4. Materials

In this study used maximum of aggregate was (¾ inch) and the water/cement was (0.45). There are two types of fibers using here. First, steel fiber reinforcement (hookedend) with volumetric fractions were (0.75, 1, and 1.5%), respectively. The properties of steel hooked end fiber are (7.8, 165ksi, 1.5”, and 29,000 ksi)specificgravity, tensile Strength, cut lengths and flexural strength, respectively. Second, the polyvinyl alcohol (PVA) with volumetric fractions were (0.1, 0.3, and 0.5%), respectively. The properties of PVA fiber are (1.3, 150 ksi, 0.75″, and 4200 ksi)specific gravity, tensile strength, cut lengths and flexural strength, respectively.

5. Results of Experimental Work

5.1 Polyvinyl alcohol (PVA)

It is well known that the dosage rate of polyvinyl alcohol (PVA)is the major contributor to properties of concrete mixture. The results of the compressive strength (fc’) for control and PVA mixtures shown in Figure (1), it is clear from this Figure that dosage rate of PVA had significant influence on the compressive strength (fc’).The fc’ increasing for dosage rate of PVA increasing.

Also, the adding of PVA with variable content had significant influence on Modulus of Elasticity (E). The results of Modulus of Elasticity for control and PVA mixtures are shown in Figure (2). It is clear from this Figure, with increase of PVA content decreasing the E. On the other hand, figure (3) show the results of the Modulus of rupture (fr) for control and PVA mixtures, it is clear from this Figure that dosage rate of PVA had significant influence on the fr.

5.2 Steel Fiber

The using of steel fiber in concrete mixture was investigating in this study. The results of compressive strength (fc’) for control and steel fiber mixtures are shown in Figure (4). It can be seen from this results that with the increasing of steel fiber content, fc’ increases clearly. On the other hand, the results of Modulus of Elasticity for control and steel fiber mixtures are shown in Figure (5). It is clear from this Figure, with increase of steel fiber content decreasing the E. While Figure (6) show the results of the Modulus of rupture for control and steel fiber mixtures.

6. Conclusion

Within the limitations of materials and testing program adopted in this work, the following are concluded:

1. The compressive strength has been increased by (20%) when adding (0.5%) of Polyvinyl alcohol concrete mixture.
2. The modulus of elasticity has been decreasing by (23%) when adding the same content of Polyvinyl alcohol.
3. Using steel fiber (1.5%) in concrete mixtures increase compressive strength by more than (145%), while modulus of elasticity slightly decreases.
4. The addition of PVA fiber by 0.5% increase of about (51%) in the Modulus of Rupture, while using steel fiber (1.5%) increase Modulus of Rupture by more than (124%).
5. The relationship between Modulus of Rupture and Compressive Strength of PVA Fiber estimated by the equations: $fr = 10.333\sqrt{fc}$, psi for PVA, and $fr = 7.855\sqrt{fc}$, psi for steel.

7. Recommended

Study the effect of adding fiber reinforced concrete in concrete mixtures on creep and aging properties.

Acknowledgments

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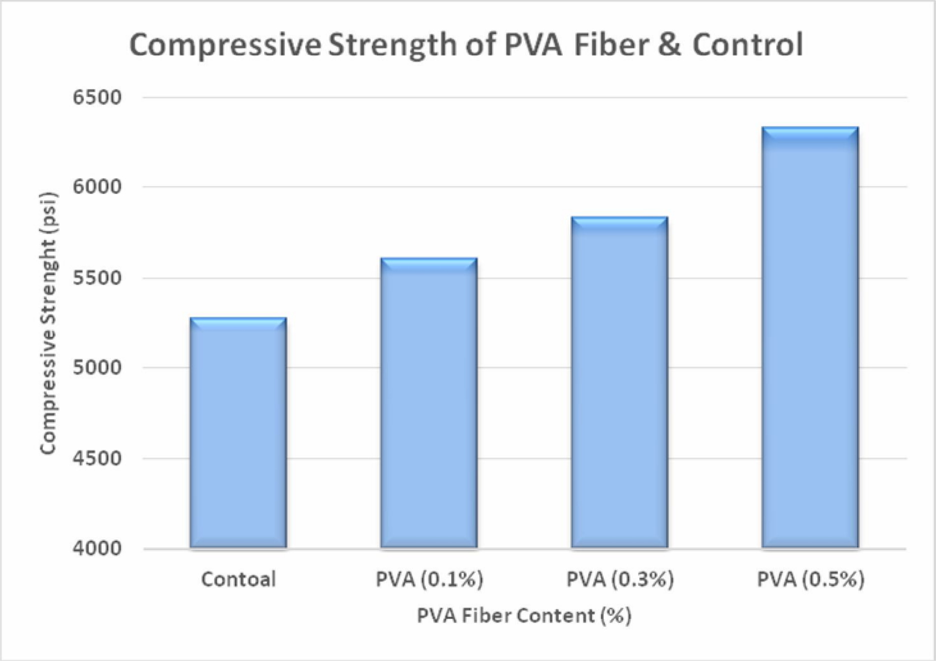

Figure (1): Compressive Strength of PVA Reinforced Fiber and Control Mixtures.

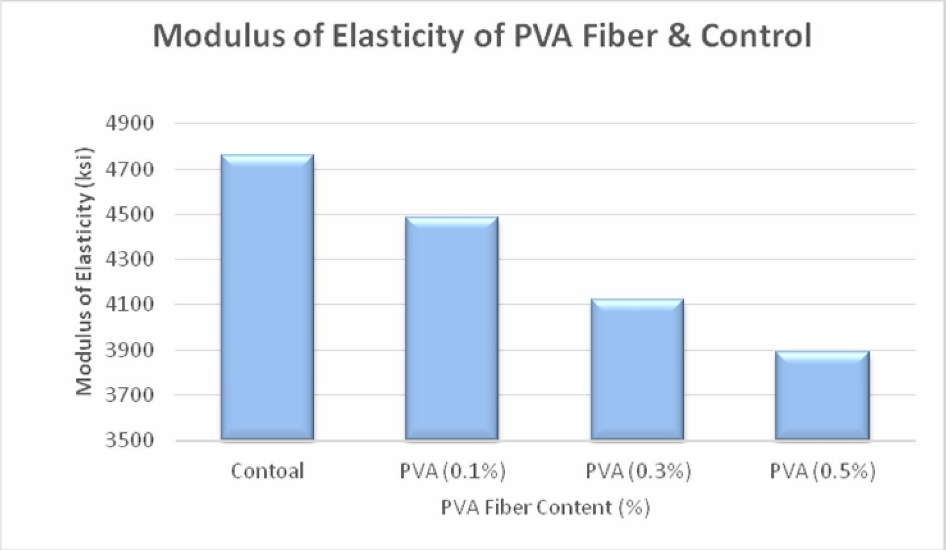

Figure (2): Modulus of Elasticity of PVA Reinforced Fiber and Control Mixtures.

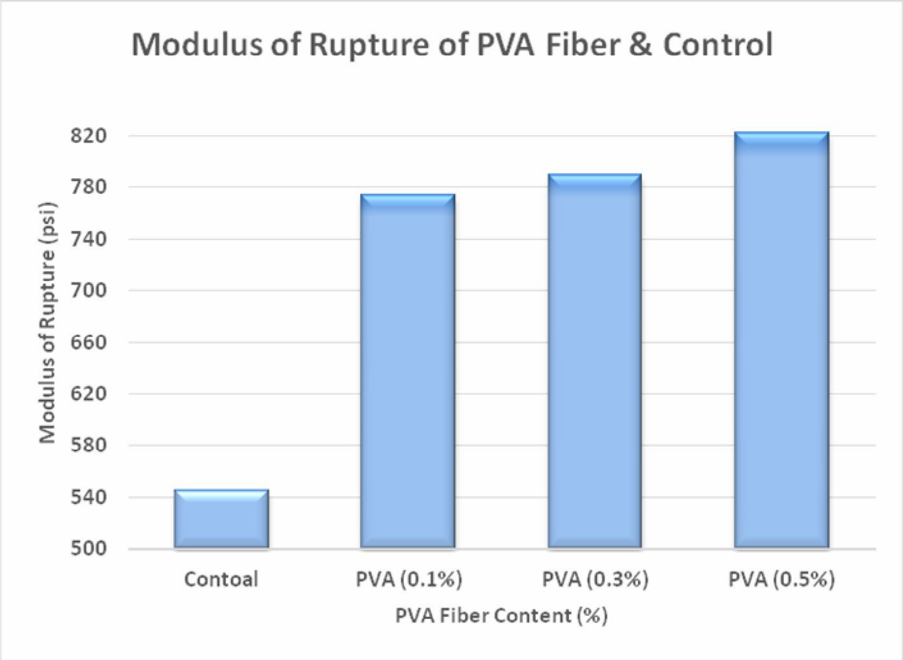

Figure (3): Modulus of Rupture of PVA Reinforced Fiber and Control Mixtures.

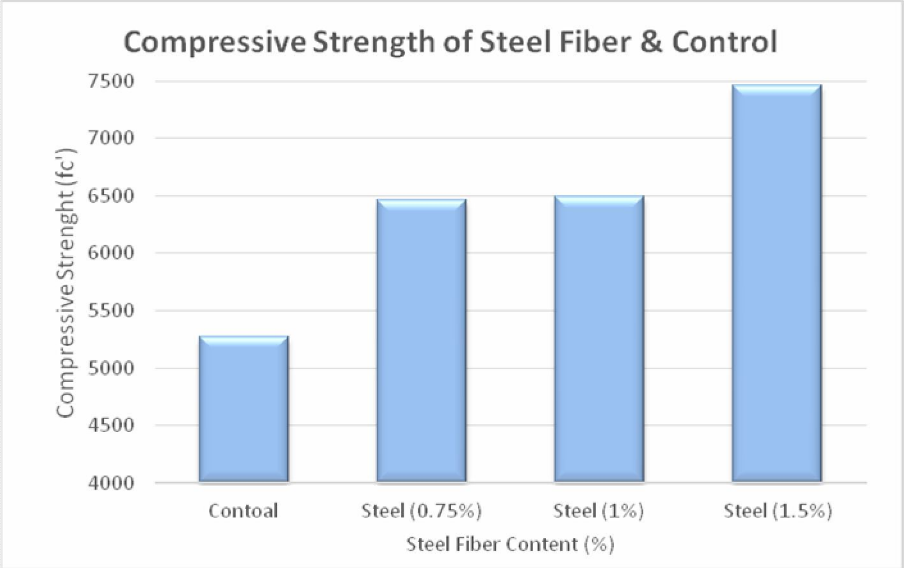

Figure (4): Compressive Strength of Steel Reinforced Fiber and Control Mixtures.

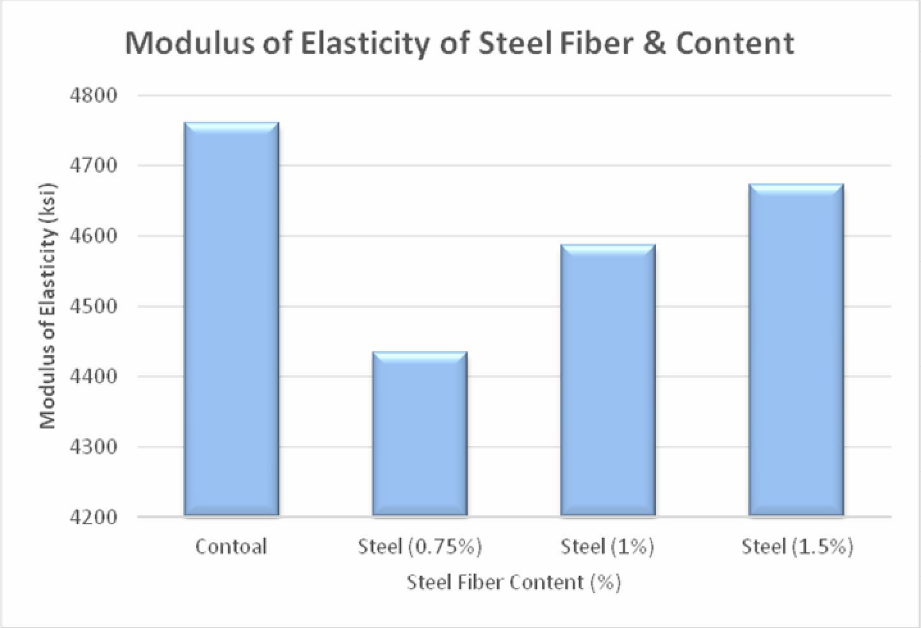

Figure (5): Modulus of Elasticity of Steel Reinforced Fiber and Control Mixtures.

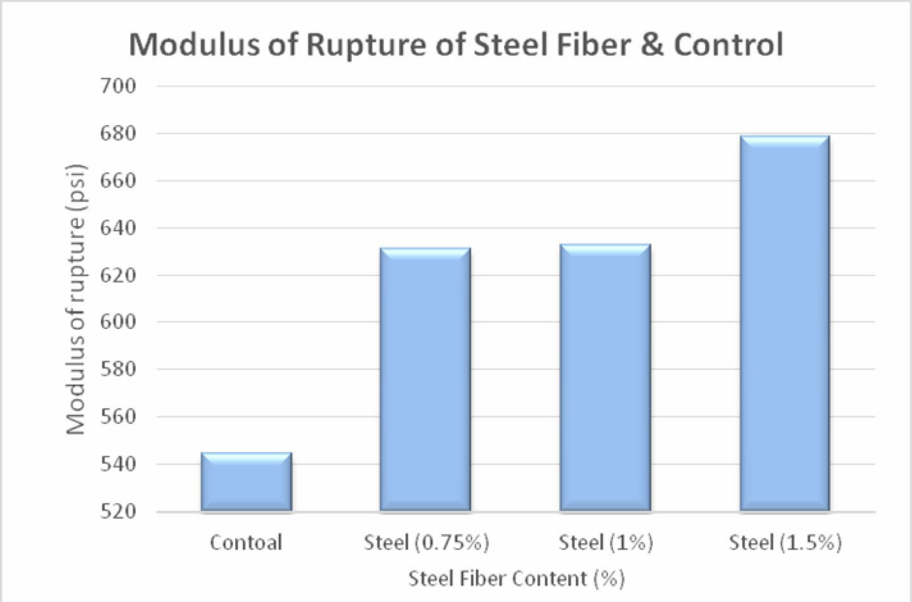

Figure (6): Modulus of Rupture of Steel Reinforced Fiber and Control Mixtures.